

THE CYCLIC LAND-SURFACES OF AUSTRALIA

A GEOMORPHOLOGICAL SUMMARY

By LESTER KING, D.Sc., F.G.S.,
University of Natal, Durban, South Africa.

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Introduction

The recent establishment of geological ages for the various cyclic land-surfaces of Africa (King 1949), and the possibility that land-surfaces of comparable age and development might be found in other parts of the world, have prompted this enquiry into the landscape history of Australia.

Without recapitulating the arguments of the above-mentioned paper, and of others which preceded it (King, 1947, 1949a), we may state simply its essential conclusions, which will be fundamental to the present study:

(a) That on the continental scale erosion cycles operate to enlarge their dominion and destroy the relics of earlier cycles, not by the 'peneplanation' of W. M. Davis, involving down-weathering, but by the processes of scarp retreat and pedimentation (combined as *pediplanation*); so that fragments of earlier cycles may long survive in the landscape as plateaux, tablelands or bevelled hill-tops. The evidence for pediplanation as the mode of development of Australian landscape is overwhelming, especially in the centre and west, where the process has been clearly described at work by Jutson (1934, pp. 233-237), and in the eastern highlands, where Craft (1933, 1933a) has remarked how smoothly-planned landscapes at different levels are separated by steep erosional scarps.

(b) That the oldest of these tablelands are Mesozoic in age and correspond to the land-surface of the parent super-continent Gondwanaland; the cyclic surface succeeding this (the Great Australian Pediplain in Australia) was initiated on the break-up of Gondwanaland in the Cretaceous period and continued current at the coasts until the mid-Tertiary; while a third group of surfaces has been generated by intermittent continental uplifts in the late-Tertiary and Quaternary.

We repeat: the above conclusions, valid for Africa, are basic also in the scientific study of Australian scenery.

Australia: Ancestral

Within Gondwanaland, the position of Australia was surely peripheral. That it was distant from South Africa is indicated by the absence of Mesozoic rocks of

Karoo type. The continent of Antarctica, one and a half times the size of Australia, possibly stood between them.

The date of separation of Australia from the parent Gondwanaland may be fixed from Western Australia. In that state, rocks of Triassic age are absent, but marine Jurassic, Cretaceous and Tertiary formations occur marginally. According to the map issued (1933) by the Geological Survey of Western Australia, Cretaceous rocks are known only south of Shark Bay, a condition consonant with the opening of a rift from the north, and closely paralleled along the eastern coast of Africa.

We may conceive, in the ancestral Mesozoic Gondwanaland, of Western Australia as a vast plain only a few hundred feet above sea-level and descending to swamps at still lower altitude in the centre of the continent. On the site of the present eastern Australia rose the bevelled stumps of late Palaeozoic mountain chains. Australian geologists (David 1932, p. 87; Bryan 1944, p. 60) have insisted that the land extended eastward, far beyond the present coast, over what is now the Tasman Sea. If so, it must have been low-lying: any Tertiary marine rocks have disappeared by late-Tertiary subsidences.

Following the disruption of Gondwanaland, and with the early eastward travel of the newly-born Australia, the central lowland was flooded by early Cretaceous epeiric seas, and the Gondwana land-surface was there buried beneath arenaceous sediments shed from the in-tilted landscapes surrounding the basined focus. Perhaps Hudson Bay is the nearest modern approach to the type of scenery involved.

Gondwana Elements in the Present Landscape

The lapse of time since the Cretaceous period, when newer erosion cycles were initiated, is so vast that these cycles have been able to destroy the 'Gondwana' surface over almost the whole of Australia (excluding the central disc where that surface was basined and buried beneath Cretaceous sandstones). Such portions of the 'Gondwana' landscape as do survive are but tiny plateau remnants standing at scarps above the wide plains of the younger cycles. Despite possible minor modification, these must be regarded as having been cut originally by agencies operating in cycles that were graded to 'Gondwana' base-levels. (Fig. 1.)

The great age of the 'Gondwana' landscape, and the immense lapse of time that must have gone to its fashioning, are indicated by the vast area over which it is eroded across very ancient granitic and Archean rocks.

The small difference of elevation (*circa* 300 feet in Western Australia and 400+ feet in parts of New South Wales) between the 'Gondwana' and 'Australian' (q.v.) pediplains also argues (a) a peripheral position at low altitude for Australia in the Gondwanaland jigsaw (a conclusion fortified by the Cretaceous inundation of the east-central region, and the Tertiary marine encroachment of Euclonia in the south), and (b) a remoteness from the African segment of Gondwanaland where the difference between the two corresponding surfaces amounts to 2000 feet.

In Western Australia. This state affords one of the finest examples of a stable region to be encountered anywhere on the globe. There has been no folding of any consequence since the pre-Cambrian, while "the late Palaeozoic sediments of the Great Desert Basin are still so unconsolidated and porous as to be an important source of artesian water, and Palaeozoic coals there are still somewhat hydrous" (David 1932, p. 14). Geographically it has been a great plain since the late Palaeozoic, but undoubtedly the prolonged erosion responsible for laying bare many

of the ore-deposits, deep-seated in pre-Cambrian granitic and schistose rocks, was accomplished even before that date.

A valuable physiographic survey of the state has been rendered by Jutson (1934), whence have been derived many of the facts quoted hereafter.

The most extensive remnants of the 'Gondwana' land-surface survive in the north-west. North Kimberley is essentially a dissected erosional plateau, the numerous 'ranges' on the map being merely the unconsumed plateau ridges between the valleys of the incised streams. (Jutson 1934, pp. 34-46). The south-western face may be a fault scarp, but the eastern boundary is less definite and leads down by erosion scarps to the Ord Plateau, the local development of the great 'Australian' cycle of erosion. Many of the streams radiate from Mt. Hann, a monadnock 800 feet above the plateau at its base, which stands at 2000 feet above the sea. On the north and west there appears to be a monoclinal outwarp towards the coast, and the country is gashed by deep valleys with vertical cliffs of sandstone.

In Pilbaraland, Murchisonia and Swanland to the south, again there is a dissected plateau, surmounted by monadnocks and sometimes exceeding an altitude of 3000 feet. The silcrete-capped Collier Plateau stands between 2500 and 2750 feet and is one of many plateaux cut through by the canyons of rejuvenated rivers. The indifference of these river courses to the general trends of geological structure indicates either superposition from an unconformable cover (of which there is no evidence) or downcutting from a previous stage of planation so extreme that the rivers ceased to be influenced materially in their courses by the structure of the bedrock. Such a stage of planation is indicated on the 'Gondwana' remnants cut without discrimination across all the local formations. In Swanland, the remnants of the 'Gondwana' plateau are termed the Mount Dale Level. The relicts tend to become smaller and less numerous from the north of the state (North Kimberley) to south (Swanland).

Farther inland, the 'Gondwana' bevel appears upon the South Esk Tableland, 300 feet above the level of the surrounding (later) great 'Australian' pediplain; and thence, far south, the same bevel is continued upon groups of flat-topped hills and ridges, usually upon granite, but sometimes upon banded ironstones. The contrast in topography is enhanced by the lateritic hill-caps (aluminous, ferruginous or siliceous as the case may be) which demonstrate clearly the origin of the summit bevel as an erosional plain of extreme age and development. The difference of elevation between the 'Gondwana' and 'Australian' surfaces is 30-100 feet, though occasionally 200 feet. This is markedly less than in the north-west, indicating a convergence of the two surfaces, leading to a crossing in the east.

In South and Central Australia. With the exception, possibly, of Arnhem Land, the 'Gondwana' surface is seldom revealed as such in South Australia and the Northern Territory because, on crossing these states towards the east, it sinks to approximately the level of the 'Australian' surface in order that it may descend yet further, and form the floor for the Cretaceous sediments of the Great Artesian Basin. Thus in the zone of crossing any features that may belong perhaps to the 'Gondwana' cycle become merged with, and indistinguishable from, those of the later 'Australian' cycle. The Burt and Missionary Plains adjacent to the Macdonnell Ranges are thus feasibly of composite origin.

Notwithstanding, the transverse drainage system of the Macdonnell Ranges itself predicates a former summit level of some sort, either normal or upwarped 'Gondwana,' and it is important to search for any fragments of earlier erosion bevels which may survive thereon. Of special interest, therefore, is Madigan's

record (1931, p. 423) of "rough, rugged gneissic country which appears flat from the air" between the Heavytree and Chewings Ranges, and of a similar area five to ten miles wide north of the Chewings Range, where there is a steep fall to the Burt Plains. Photographs of the James Range to the south also favour an earlier ('Gondwana') planation of the crest there. No earlier bevels have been recorded from the Musgrave Ranges though Mt. Woodruffe, the highest point in the state, rises to nearly 5200 feet. Perhaps we are dealing here with a locally upwarped portion of the 'Gondwana' surface, renewed, perhaps, on the site of a still more ancient warp—a suggestion which would account also for the unusual height of some of the ranges (2000 feet) above the plain.

The 'Gondwana' bevel may, of course, locally be exposed as a resurrected surface by stripping of once-overlying Cretaceous sediments, but examples do not seem to have been quoted in literature.

In Victoria. Victoria is well documented and the physiographic evidence has been ably handled by Hills (1934, 1940). Four cyclic phases or groups have been made out, the earliest of which (Cretaceous) corresponds to our 'Gondwana' cycle.

The relicts of a once-planed 'Gondwana' surface survive upon resistant Devonian lavas of the Warburton-Healesville-Marysville district, as a high prolongation from the main divide south-eastwards towards Mt. Baw Baw. Mt. Buffalo and the Bogong High Plains represent the same cycle farther to the east upon other resistant rock masses. These districts are extensively dissected in the succeeding 'Australian' cycle which, according to Hills' diagrams, is developing by the processes of pediplanation. The elevation of the plateaux is from 3500 to nearly 6000 feet, indicating differential uplift during their subsequent history.

The Cretaceous age assigned to the bevels by Hills is derived from the observation that the former plains had been extensively dissected in the 'Australian' cycle before the eruption of the Older Basaltic Lavas which lie at Berwick, Narracan and Pascoe Vale upon pipe clays of Oligocene age. The age so derived is consonant with that of the similar small plateau remnants in similar situations relative to the great 'Australian' pediplain in other states. There is, however, some question whether two distinct phases of the Older Basalt may not exist.

Doubtless, at the time of subsidence in the interior to receive the Cretaceous marine sediments, the Victorian divide formed the south-eastern rim of the basin.

In New South Wales. Excepting a moiety in the south-west, New South Wales has not been beneath the sea since Mesozoic times and the present topography has been developing since the Cretaceous at least. There has thus been ample time for planation, and plains are widespread, often converted into tablelands by circum-denudation in much later cycles of erosion. The country should be ideally suited to the mapping of cyclic erosion surfaces, though there is some doubt as to the extent of tectonically induced relief in some localities (Cotton 1949, p. 280).

Small tableland fragments in the landscape of New South Wales have been ascribed by Süssmilch (1937) to a Cretaceous peneplain which suffered a late- or epi-Cretaceous uplift and was subsequently dissected by a new cycle (the 'Australian') which also attained extreme planation. These fragments are thus comparable with the residuals of 'Gondwana' landscape which surmount the main divide of Victoria, and may be assigned to the same ancient cycle of erosion. Examples are: towards the Queensland border, the tableland standing at 4000 feet, above the later plain of the 'Australian' cycle at 3000 feet; in the centre, the higher parts of the Blue Mountain Tableland; and in the south the 'pre-Tertiary' plateau at 4000 feet or so about the sources of the Murrumbidgee River (Craft 1933, pp.

230, 236). Some of the higher bevels and terraces may be due to earlier phases of the 'Gondwana' cycle, or to local upwarps of the region during the currency of the main 'Gondwana' cycle of erosion (King 1949, fig. 1).

In the north the 'Gondwana' surface stands locally at 400 to 1500 feet above the great 'Australian' pediplain, an intervening tilt to the west being shown by this variation.

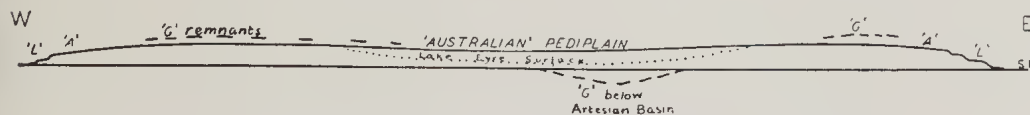


FIG. 1.—Diagram to illustrate the relationship of surfaces suggested in text. 'G' = 'Gondwanaland.' 'L' = 'Lake Eyre' and other later cycles.

In Queensland. In parts of the Great Dividing Range the 'Gondwana' surface has been exhumed locally from beneath the Cretaceous cover. It transects early Mesozoic terrestrial strata, the exposed ends of which form the intakes for the Great Artesian Basin. Yet this resurrected landscape is nowhere prominent, and most has been destroyed in the 'Australian' cycle which has cut flatly across it.

Elsewhere, the 'Gondwana' land-surface is not expressed topographically, though Whitehouse (1941, p. 1) notes it in the fossil state: "Unconformably upon the Mesozoic surface are early Cainozoic beds in the south-west and occasional remnants of late Cainozoic beds in the east."

The 'Australian' Pediplain

All the states of the Commonwealth display abundantly wide, rolling plains, frequently capped with ferruginous or siliceous "duricrust" (Woolnough 1927, pp. 17-53). Many of these are portions of a formerly even more widespread continental surface which we shall call the 'Australian' pediplain. Its appearance in the Eocene has been described by David (1932, p. 172): "We see that almost the whole of the Commonwealth has been reduced to one of the most perfect peneplains imaginable. . . . Only perhaps along the central and southern coastal belt of Queensland, where Laramie movement had been intense, and possibly in the sill-displaced blocks of Tasmania, have any elevations escaped base-levelling."

The 'Australian' cycle of planation made its *début* with the fracturing of Gondwanaland and the assumption, by Australia, of independent continental status. New base-levels were created, in part by monoclinical downwarping of the margins (e.g. Western Australia), and in part by regional subsidence with peripheral tilting (e.g. Central Australia). On the whole the difference of elevation between existing 'Gondwana' and 'Australian' surfaces is small.

All available evidence insists that the mode of development of the 'Australian' land-surface was by river incision, scarp retreat and pedimentation; except in the central disc, where it was originally largely aggradational. So effectively have the pediplanational processes operated that, as we have seen, only a few minor relicts of the earlier 'Gondwana' land-surface survive in the great breadth of the Australian continent; and though the 'Australian' pediplain has itself been attacked by later cycles of erosion, it is still more widespread than any other.

The period during which the 'Australian' cycle was current at the coast extended from the Cretaceous to the Oligocene or Miocene, so that in its mode of develop-

ment, relative distribution and age limits it corresponds to the 'African,' 'Indian' and 'South American' land-surfaces described elsewhere (King 1950).

In Western Australia. The vast plateau forming almost the whole of the state stands approximately 1500 feet above the sea, and is encompassed upon three sides by relatively narrow coastal plains. Upon the fourth (eastern) side it continues without significant alteration, though at slightly lower elevations, into Central and South Australia.

Over the whole of this vast territory the mode of development has been by scarp retreat and pedimentation, and the few residual hills which rise from the general surface do so abruptly at erosional scarps. Such are the only eminences apart from possibly a few fault blocks (Stirling Range) (Jutson 1934, p. 6). Certain of the residuals bear the summit bevels of the 'Gondwana' cycle standing from 30 to 300 feet above the level of the 'Australian' pediplain.

Much of the general elevation of 1200 to 1500 feet achieved by the Western Australian plateau must be ascribed to uplift in Tertiary time (*q.v.*). Slight irregularity of uplift, like the warp extending from Victoria to the Nullarbor Plains, may have been responsible for the subdivision of the plateau into areas of exterior drainage, and interior drainage into different centra. The alluvial plains of some of the rivers of the interior may also be due as much to back-tilting as to the local abundance of waste.

The Ord and Fitzroy river basins exhibit the main or 'Australian' pediplain, lower than the 'Gondwana' surface of North Kimberley and Pilbara. Northwards, the relations between them have been complicated by local upwarps of both surfaces. Southwards, the pediplain becomes progressively more widespread at the expense of the earlier bevel, until it forms the whole of the wide, arid expanse typical of the inland scenery of the state. There are no true rivers in the far interior, for the rainfall is often less than ten inches per annum. Vertical corrosion is thus at a minimum and, apart from the sand country, surface accumulations of detritus are few. Even the lateritic duricrust is relatively thin.

The surface descends irregularly eastwards and south-eastwards, between altitudes of 1000 and 2000 feet. Slopes are generally between two and five feet per mile. To the eastward and north-eastward the pediplain is partly masked by accumulations of sand.

In the extreme south-east (Jutson 1934, p. 127) is the Nullarbor or Eucla region, of almost horizontally-disposed Miocene marine limestones. From the coastal cliffs (200 to 400 feet) the limestones rise slowly inland to 1000 feet, with 450 to 650 feet of the Trans-Continental Railway. The plain is almost incredibly flat, and the railway runs for 330 miles without a single curve. This flatness, combined with the marine types of sediment involved, suggests that the surface may follow the original depositional form despite later sub-aerial erosion. The limestone is cavernous and the region is without flowing rivers, so that sub-aerial erosion has, in the dry climate, been at a minimum.

Little is known of the relation between the limestone surface and the 'Australian' pediplain, for the region is inhospitable and difficult of access. Moreover, it would be exceedingly difficult to decide without extensive survey whether is involved (a) a single erosional surface ('Australian') bevelling older rocks and Tertiaries alike, (b) two surfaces: the 'Australian' pediplain continuing below the limestones and a newer surface, either depositional or erosional, forming the limestone plain, or (c) an earlier phase of the 'Australian' cycle passing below the limestones while a later phase of the same ('Australian') cycle cuts across them above, after elevation.

Presumably the angle between the two cyclic, or two sub-cyclic, surfaces would be so small as to be difficult of measurement in the field. For the present, while retaining all three of the above working hypotheses, we may regard the second as most feasible, with the sub-limestone surface as an early phase of the 'Australian' cycle and the supra-limestone surface a *depositional* equivalent of a 'late-Australian' phase on the continuously exposed land to the north.

In South and Central Australia. The exceptional hilly tracts within the state are limited to the ancient, dissected strike-ridges of the Macdonnell and Musgrave Ranges in the heart of the continent, and the Flinders and Mt. Lofty Ranges, a series of horsts, in the south. The rest of the region consists of plains, in which two levels are prominent, one above and one below 500 feet. The upper is the 'Australian' surface which enters without alteration across crystalline terrains from Western Australia. These plains slope gently eastward and south-eastward until they are encroached upon at low scarps by a younger ('Lake Eyre') cycle. The 'Australian' cycle passes also across the Cretaceous rocks of the Great Artesian Basin; but here a younger cycle is dominant and the 'Australian' pediplain, heavily lateritized, truncates the flat-topped 'tent hills' which rise sharply from the younger plain.

Thus the 'Australian' pediplain here constitutes a plateau and links up with a similar plateau forming the southern part of the Northern Territory, and extending to north and south of the Macdonnell Ranges as the Burt and Missionary Plains. Little information is available regarding the topography of this territory, but away to the north the 'Australian' pediplain makes the striking summit bevel of the Barkly Tableland (Whitehouse 1940a), on which feature it is carried into western Queensland.

Photographs reveal that the Musgrave and Everard Ranges of South Australia rise as inselbergs from smooth pediments in a manner that betrays unmistakably their origin under a cycle of pediplanation involving scarp retreat. The ranges are low and scattered and are typical inselberg monadnocks in a vastly eroded landscape. Wind has been claimed as their chief eroding agent, but even allowing for some change of climate during the long period of their existence, the drainage systems and forms of the hills and of the pedimented plains reveal the dominant operation of sheet water-flow. Only in the great sand deserts to the north-east and north-west does wind hold the upper hand in landscape development.

Characteristic upon the 'Australian' pediplain, in South Australia as elsewhere, is the 'duricrust' or lateritic covering. It is best seen, perhaps, where much of the surface has been destroyed in younger erosion cycles and the pediplain is left truncating innumerable residual hills, the mesa-like appearance of which is enhanced considerably by the hard, accordant caps of silcrete or laterite (e.g. near Oodnadatta). The age of the Australian laterite, as far as can be judged from associated fossils, ranges from Cretaceous to Pliocene (cf. Africa (King 1949)), and there has, locally at least, certainly been more than a single period of formation (Whitehouse 1941, p. 5). From analogy with similar deposits in Africa we may accept that the deposits have been formed semi-continuously over a great lapse of time rather than in brief, intense periods of greater rainfall. As stated elsewhere, time and seasonal drought, rather than pluviation, seem to be the keys to the formation of laterite and its siliceous, ferruginous and calcareous congeners. Where the lateritic armour of the pediplain has been fragmented, a rubble of intractable 'gibbers' lies strewn across the surface.

The duricrust is important, for it indicates that the 'Australian' surface has possibly survived through several geologic periods without significant lowering under erosion. There is, indeed, little reason why undisturbed land-surfaces which have once attained an advanced stage of planation should be materially lowered however long they are exposed to the elements.

If, as is believed, the 'Australian' cycle was initiated as early as the beginning of the Cretaceous period, it was doubtless well advanced before that period closed. Doubtless, also, the lacustrine, estuarine and marine Cretaceous sediments of the continental interior were derived as the debris shed from the surrounding, differentially elevated country under the earlier, vigorous phases of the cycle. Following the disappearance of the inundations, the later phases of the 'Australian' cycle were extended, in the interior, over the sediments the earlier phases had supplied. The changes effected would probably be slight; and the aspect of certain of the great plains, where they have not been attacked by younger cycles, may not differ markedly from the original depositional aspect of the late Cretaceous. Herein is a useful principle: if erosional surfaces can, and do, survive almost indefinitely under favourable conditions, why should not depositional surfaces survive also?

The Gawler Ranges, south of Lake Gairdner, are an assemblage of residuals upon the 'Australian' pediplain. As such, they owe their existence in parts to the superior durability of the pre-Cambrian felspar porphyries of which they are composed. They are, naturally, ancient, and some evidence of Cretaceous glaciation has been forthcoming from this locality, perhaps incurred as Australia in its drift from Gondwanaland passed its southern nadir on a great circle course (King 1944, p. 8). But the modern ranges are regarded as due also to an upwarp, probably late Miocene in age, co-linear with the Peterborough Plateau and the Olary Ridge to the east. The latter of these is a broad, upwarped plateau (1000-2000 feet) with the great rolling surface of the 'Australian' cycle of erosion. Stream courses upon it are often (according to Howchin) "uncertain and anomalous, and may change direction from one flood time to another."

In Victoria. Under other titles, the 'Australian' pediplain has been identified in Victoria by many authors. Near the divide, where the 'Gondwana' relicts still survive, there has been described an ancient topography of hills and valleys which represents an upland phase of the 'Australian' cycle. Towards the south, and presumably to the interior, there was much flat land. Thus, when the Older Basalts were poured out, converting the gravels of the stream-beds into deep leads, they were confined to the valley-floors up country, but spread much more widely as sheets on the lower country (Hills 1934, pp. 161-2).

Much of the 'Australian' surface of Victoria has been lost to later cycles of erosion, or has descended under tectonic influences to low level where it has been blanketed by marine or paludal formations (*q.v.*). Nevertheless, it was upon the 'Australian' surface in late Cretaceous or Early Tertiary time that the main divides and stream courses of the state were first established, following differential movements in the Murray Basin to the north and Bass Strait to the south. (Hills 1940, p. 271.)

In New South Wales. The dissection of the 'Gondwana' surface, begun in the late Cretaceous, culminated, according to Süssmilch, in the Miocene with the usual broad planation of the 'Australian' cycle across New South Wales. In the north-west and south-west of the state wide tablelands still carry the hallmark of this cycle in their summit plains; but the best undissected areas are probably those adjacent to the Great Divide (Süssmilch 1937, p. xxvii). Thus at Emmaville,

towards the Queensland border, the surface stands at about 2900 feet on granites and porphyries. It possessed valleys some 300 feet deep in which deep leads and plant-bearing beds of Eocene age* are preserved below basalts equivalent in age to the Older Basalts of Victoria. Tilting north-eastward shows in the attitude of the surface, which descends from 3000 feet at Hargreaves to 2000 feet at Wellington and 1500 feet at Dubbo. The main tableland surface of the Blue Mountains belongs to the 'Australian' cycle, and in the south the Monaro plain at 3000-3300 feet (Craft 1933, p. 232). The surface, indeed, slopes west through much of the state, presumably by later dishing of the centre of the continent.

Other differential movements accompanying the development of the Murravian Gulf ended the 'Australian' cycle there by drowning it below sea-level. The same movement no doubt altered the courses of many of the rivers, e.g. Darling (David 1932, p. 89).

In Queensland. Western Queensland was covered by Cretaceous seas and swamps, and the accumulations of that far-off geography are still almost horizontally disposed. In the absence of any marked deformation the 'Australian' pediplain has thus had full opportunity for development. It is admirably displayed upon the so-called Great Dividing Range, which is essentially a zone of the pediplain so gently upwarped that a number of basins of centripetal drainage occur even at the crest of the Divide itself. It is encroached upon by younger cycles operating up the shorter streams of the eastern coast, but occasional tablelands still survive on the interfluves (e.g. Mt. Morgan Tableland). Süssmilch (1928, pp. 128-129) has explained the scarps bounding the tablelands as due to faulting. Without traversing his arguments, we may prefer to interpret his data in the light of the pediplanation cycle operating to newer base-levels, and find only the usual retreating scarps of younger erosion cycles cutting with relative indifference across various rock series, after being generated in conformity with a drainage pattern partly controlled by geologic structure.

As elsewhere, the pediplain is veneered with laterite ('duricrust') and residuals of this veneer surmount the very divide. Clearly, when the laterite accumulated, the divide was not in existence. On the Alice Tableland the laterite sheet, virtually unbroken, covers an area of over 20,000 square miles, and illustrates very clearly the pristine condition of the pediplain. Local opinion has tentatively regarded the laterites as Pliocene in age (Whitehouse 1940, p. 17); but there seems no reason why the bulk of the deposit should not be vastly older as is the case on corresponding land-surfaces in other continents (King 1949). In favour of this interpretation is the fact that basalts poured out at the crest of the divide are younger than the laterite and yet have been dissected; and also the vast destruction of the laterite cover carried out by younger cycles in the west, and the erosion of the pediplain accomplished by the rivers of the eastern slope. The youngest rocks transected by the pediplain are those of the early Tertiary Eyrian Series in south-west Queensland.

From the divide, the 'Australian' pediplain slopes gently westward until it is dissected by the valleys and plains belonging to younger erosion cycles. There is a wide area in the basins of the Georgina, Thompson and Cooper Rivers over which the dissected pediplain appears as innumerable accordant mesas, each bearing the appropriate cap of laterite, e.g. Boulia. Often nothing is left but a scattering of

*Attention should be drawn to Süssmilch's discussion of the value of fossil leaves for determining the ages of Australian Tertiary beds. Apparently, accurate dating is not possible by this means.

'gibbers' upon a few divides, and the vast 'Downs' and older alluvial plains of western Queensland have been developed by the destruction of the earlier 'Australian' pediplain. On the Barkly Tableland at the western borders of the state the 'Australian' cycle, cut on ancient limestones, passes out of the state.

Many of the drainage patterns originated upon the pediplain of the 'Australian' cycle, and the Warrego drainage to the Darling has been quoted as an example of this. Some of the gorges of the Gregory River through strike-ridges of pre-Cambrian rocks, and certain reaches of the Leichhardt, also probably originated by incision from the former 'Australian' land-surface, though no trace of laterite remains locally to point its former presence.

Seldom does any marked topographic feature separate the interior drainage from that external to the Gulf of Carpentaria. The headwaters of the Diamantina are separated from the gullies of the northern drainage only by a plain a mile or two wide. Here again gentle warping has probably initiated the divide, though southward migration under headward erosion has also doubtless played a part.

The 'Lake Eyre' and Other Later Cycles

The 'Great Australian Pediplain' provides the fundamental topographic datum for the Commonwealth, but over much of the continent it has been destroyed during subsequent erosion cycles, and is succeeded by younger suites of land-forms. These cycles have been initiated principally by continental uplifts and deformations, the first of which seems to have been of late Oligocene or Miocene date. The uplifts were not uniform, and differential and opposed movements are often shown at the coasts.

There is naturally a greater range of local variation between the facets of these later cycles which would be fascinating to work out in detail. But this we must for the present eschew, and the various cycles of Miocene or post-Miocene initiation will be treated collectively.

We must pause, however, to note an important feature of these cycles. The drainage of more than half Australia is endoreic. Topographic features over this vast area will thus be developed independently of true oceanic base-level, but instead with reference to a host of local base-levels of great or of little importance. The chief of these is the base-level provided by Lake Eyre and we shall refer to the most important group of the post-Australian cycles, succeeding the 'Australian' cycle itself, as the 'Lake Eyre' cycle, recognizing, however, that it is not single but multiphase.

In Western Australia. The altitude of the 'Australian' pediplain (1200-1500 feet) betokens a subsequent elevation of nearly a thousand feet in late Tertiary time. This estimate is supported by the record of Marine Tertiary (Miocene) rocks standing 900 to 1000 feet above the sea at Norseman, near Lake Cowan, 120 to 150 miles from the present coast. In the Eucla Basin, too, marine Tertiaries rise to nearly 1000 feet at their inner edge. Oligocene marine sediments also rise to 1000 feet above the sea west of Exmouth Gulf; but here much of the uplift is local, for the structure is anticlinal.

The uplift of Western Australia was not uniform. Jutson (1934, p. 203) records: "The plateau on uplift would appear to have had a vast undulating surface due to a series of very gentle folds or warps, broken occasionally by fault-scarps." He refers also to great flat domes in Pilbaraland and North Kimberley.

The divide separating the oceanic from the interior drainage is also feasibly a result of uneven uplift of the 'Australian' pediplain. The descent to the coast is gradual in Murchisonia but southward takes place suddenly at the Darling scarp, below which marine Cretaceous beds appear at intervals (500 feet altitude at Gingin). Of this scarp, Dr. D. W. Johnson has expressed the opinion that it may have developed from a monoclinical fold of the coastal zone, with differential erosion upon rocks of different degrees of resistance. Prider (1945) also regards it as a scarp due to differential erosion.

But the best evidence of intermittent uplift comes from the carving of 'partial bevels' at elevations between that of the 'Australian' pediplain and features due to the present cycle of erosion. Best known of these is the 'Meckering Level' at 800 feet along valleys incised into the Darling Plateau ('Australian' cycle) of the west; and there are also erosional terraces at 450 feet and 250 feet respectively above the sea. Woolnough has assumed erosion in the Meckering Level cycle to have been contemporaneous with the Norseman limestone. No close correlation has been made between the stages of uplift in the Eucla region and the other, lower, bevels of the western coast.

In the interior of Western Australia the 'Australian' pediplain has been but little dissected by later cycles.

In South Australia. The second existing planed surface of central and southern Australia stands at lower elevation, and is younger than the 'Australian' pediplain. This later cycle has been induced partly by continental uplift and partly by the sinking of interior basins, of which the Lake Eyre basin is the largest. That sinking was actual, and not merely relative, is proved by the depression of Lake Eyre which is itself below sea-level, though recent marine formations do not appear anywhere within the basin.

Events post-dating the main development of the 'Australian' pediplain may thus for convenience be studied under two heads, accordingly as they affected regions of endoreic drainage, or of exoreic drainage.

During the early Tertiary era, great rivers flowed southward through Central and South Australia; then, probably in Miocene time, two profound, though gentle, movements combined to sever these courses before they reached the sea. The first was the immense downsagging of Lake Eyre and the second was an arching along an east-west line, of the Gawler-Peterborough-Olary upwarp which locked in on its northern side Lakes Gairdner, Torrens (in part also a sunken graben) and Frome (Fenner 1931, p. 26). Thus most South Australian rivers now terminate not at the sea, but in huge, alluviated depressions, which themselves form some of the most significant features of the geography of the state.

The Lake Eyre basin, in particular, functioned as a new base-level, and congruent cycles of erosion have operated to destroy the great 'Australian' pediplain over a vast proportion of the interior. The new plains, mainly erosional but in part depositional, make the most widespread landscape in South Australia. The surface has been partly silicified, as at the opal fields of Coober Pedy. Remnants of the earlier 'Australian' surface often form accordant, flat-topped, steep-sided 'tent-hills' or mesas, capped with silcrete, as in the same locality (Fenner 1931, p. 29), and serve to demonstrate the depiained origin of the later, or 'Lake Eyre,' cyclic land-surface. The highest of the 'tent-hills' stand about 200 feet above the lower plain, as near the boundary with the Northern Territory (Madigan 1936, p. 63).

Across the landscape of the 'Lake Eyre' cycle, the rivers, loaded with debris and adapted to carry rare floods, make the frequently braided and reticulate patterns

(Cooper, Diamantina) which Madigan (1936, p. 139) has described as so typical a feature of Central Australia: "Though mighty rivers begin their long journey to Lake Eyre from 600 miles away, yet their courses are indefinite in South Australia for hundreds of miles and they have countless swamps and minor lakes to fill before their waters can reach Lake Eyre. The country north-east from Lake Eyre for 250 miles, to the Queensland and New South Wales borders, is a great alluvial plain, really the inland deltas of the Diamantina and Cooper." In some districts are also long parallel sand-dunes.

Lake Eyre is the focus of this vast inland drainage system. The land-surface of the 'Lake Eyre' cycle is thus largely depositional, but the deposition follows an earlier phase in which erosion destroyed the greater part of the earlier 'Australian' pediplain. Without question, the 'Lake Eyre' cycle is multiple, and erosional and depositional phases have alternated over a long period; but insufficient data are available to distinguish the individual phases yet with any degree of clarity.

South of the Gawler-Olary warp, and continuous with the Nullarbor region (Euclonia) on the west, is the Mallee, a region of plains composed of Miocene marine strata. Credibly the sinking of the Mallee was contemporaneous with the sagging of the Lake Eyre basin: a correlation which suggests a mid-Tertiary date for the initiation of the 'Lake Eyre' cycle in the interior. Certainly this accords well with the vast amount of erosion accomplished, in an arid to semi-arid environment, by the 'Lake Eyre' cycle, and the fact that the cycle transects locally in the interior early, but not late, Tertiary strata.

There was possibly some tilting southwards of Australia as a whole about the same date (Miocene) which, be it noted, approximates also the period of folding of the great ranges of New Guinea (Burdigalian). Be these matters as they may, we observe that by the end of the Oligocene the 'Australian' surface had attained extreme planation, and by the Miocene had sunk to the south in a broad Euclonian-Murravian Bight extending far into Victoria (Hills 1940, fig. 349).

After an interesting interval in which brown coals (Yallournian) were deposited (Mawson 1936, p. lxii), three hundred or more feet of limestone accumulated in this bight before the region rose gently again in the earliest Pliocene. The upper, depositional surface of the limestone formed the primitive state of the broad plains of the present-day Mallee. In places the limestones have since been wholly stripped to reveal the fossil surface of the 'Australian' pediplain cut across the crystalline pre-Cambrian undermass.

Irregularity of uplift, and perhaps later Kosciusko movements, formed shallow basins, now largely filled with alluvium and sands (Fenner 1931, p. 59).

The structurally similar plains south of the Mallee show a post-limestone (?Kosciusko) faulting parallel to the coast, and the region is one of slow, intermittent rise with former coastal dune ridges parallel to the existing Coorong (Fenner 1931, p. 59).

Westward, the Mallee passes into the comparable level treeless expanse of the Nullarbor limestone plains, in this state reaching to 500 or 600 feet above sea-level. This, as we have noted, may well be a surface of deposition, innocent of sub-aerial planation since its emergence on account of the prevailing extreme aridity and the porous nature of the limestone bedrock.

On the opposite side of the continent, in the Northern Territory, a post-'Australian' cycle again appears. Thus, north of the Macdonnell Ranges, the Burt Plains ('Australian' cycle) stretch as far as Hann's Ridge and Ryan's Well (Madigan 1936, p. 99), where the country becomes rougher under dissection by a

new cycle. The country around Central Mt. Stuart is again like the Burt Plains, but thirty miles beyond the country is once more dissected. Near Barrow Creek, flat-topped hills of rotten granite, capped with duricrust, rise to the level of the 'Australian' pediplain with considerable resemblance to the topography of the Lake Eyre basin.

Thus a new cycle is hereabouts plainly etching its way into the great 'Australian' pediplain. As none of the drainage of this region is tributary to the sea, but broad basins exist, the new cycle may well have been induced by local downwarps such as the well-known Polygonum Swamp. The cycle may provisionally be correlated with the 'Lake Eyre' cycle.

In the small drainage systems of the north, tributary to the Timor and Arafura Seas, a cycle younger than the 'Australian' is again apparent, as north of the Barkly Tableland.

The Kosciusko block-faulting finds expression within the state in the Mt. Lofty and Flinders Ranges and the adjacent Yorke Peninsula, and the sunklands of Spencer and St. Vincent Gulfs. The total movement on the faults is of the order of 3000 feet. Remnants of the Miocene marine limestone remain upon several of the lower blocks: Port Willunga, Port Noarlunga, Myponga on the Para block behind Adelaide, and at a height of nearly a thousand feet at the head of the Hindmarsh River and near Mt. Mary. From the higher blocks the marine cover has been stripped under erosion revealing a smooth crestline of the resurrected 'Australian' cycle, modified to some extent by mid-Tertiary wave-erosion. From the general level, Mt. Lofty (2334 feet) and other higher points rise as residuals. Certain of the intermediate blocks, such as the Sturt Block and Belair Block, also bear the stripped 'Australian' surface and serve delightfully in the interpretation of the scenic evolution of the ranges.

There is consistent evidence of a period of local planation following the first Kosciusko movements and prior to the last Kosciusko movements (Fenner 1931, pp. 43-48). Some of the summit bevels can, in that case, be assigned to this "anteconsequent" planation, and certain of the drainage features be better understood thereby; but nothing in this hypothesis conflicts with the major plan of continental landscape evolution as we have envisaged it to be. It is a complication wholly expectable in a region marked by strong late-Tertiary differential movements. Other drainage changes, perhaps allied, have been described by David (1932, p. 91).

The Flinders Ranges are the northward continuation of the Mt. Lofty Ranges, yet they differ scenically because of the more arid environment which renders them bare and inhospitable. The ranges continue northward until they finally plunge below the sediments of the great interior basins.

In Victoria. Southern Victoria experienced the same Miocene-early Pliocene depression of the 'Australian' pediplain that affected the whole of the southern coast of Western and South Australia and formed the Murravian Gulf. As in South Australia, brown-coal swamps appeared in Gippsland (the Yallournian brown coal is 500 feet thick (Singleton 1939, p. 49)), and were succeeded by a full marine incursion extending to the southern flanks of the Central Highlands. Only the South Gippsland Highlands, Wilson's Promontory, the Mornington Peninsula and the Otway Ranges projected as islands above this shallow sea.

At least one local, partial surface, the Nillumbik Plateau, was carved at this time. Of this, Hills writes: "It is clear, however, from the fact that the Older Basalt residuals were left on the erosion surface, that no widespread erosional plain

was produced. The Nillumbik Penepplain is best regarded as a modified pre-Older Basaltic Terrain ['Australian cycle'] . . . of low relief." It is now revealed as a stripped fossil plain where the overlying Tertiary sands have been removed.

General uplift, accompanied by local warpings, supervened at the close of the early Pliocene (post-Kalimnan). The sea retreated and most of Victoria was re-exposed to sub-aerial erosion, at a somewhat lower level than the present. The fluviatile and marine sands of the Middle Tertiary were then carved, with the older terrain, into a matureland. The valleys were later overlaid by outpourings of Newer Basalt (Pliocene) which may be seen around Melbourne. In the western districts (Colac) wide lava plains spread across the country, the outposts of volcanic activity extending even into South Australia.

In the interior the sea had vacated the Murravian Gulf, since when much of the region (Mallee) has been traversed by late-Pliocene and Recent sand-dunes. No streams rise in the Victorian Mallee, and were it not for the great size of the Murray River and certain of its tributaries which rise in more humid regions, there would doubtless be no outflow at all from this region. Erosion by running water has thus produced relatively little modification of the original late Tertiary depositional plain.

South and west of the Mallee, the extensive alluvia (in places 200 feet thick) of the Wimmera overlie the slightly-dissected marine deposits of the Murray Gulf. Fluviatile effects have been aggradational rather than degradational.

Apart from minor touches, mainly along the coast, the configuration of Victoria was completed in the Kosciusko orogeny, when the final elevation of the Central Highlands was accomplished, with tilting of the torrent gravels upon their flanks; the block-faulting and doming of the Southern Highlands arrived at their present status; and finally the sea retreated from the Murravian Gulf.

For Quaternary time it is only necessary to record erosion of the upwarped and upthrown blocks, the drowning of Bass Strait with the formation of Port Phillip and the Gippsland Lakes, and the accumulation of extensive coastal dunes.

In New South Wales. The dating of Tertiary tectonic events is rendered difficult by the virtual absence of marine Tertiary strata from the state. Even the plant fossils seem to be of limited value for correlation (see previous note).

But the tablelands of the 'Australian' cycle are succeeded by a later, multiple, tilt-induced ('Lake Eyre') planation west of the main divide, and by a number of later cyclic episodes in the east (Craft 1933a). The Yass-Canberra Plain at 2000 feet, which is possibly an example of this planation, bears in its upper valleys flows of Newer Basalt. Deep-leads attest the remote age of many of the valley incisions. Süssmilch (1937, pp. xii, xvii) has regarded all the deep-leads as of the same age, but this view is perhaps due for revision. Certainly, the frequency with which deep-leads, or rather valleys 200-400 feet deep, occur in the planed landscapes of New South Wales suggests gentle tilting, probably repeated, to the west.

Deep-leads of late date occur upon the tableland at Gulgong, which stands at only 1600 feet above sea-level. Floras from the deep-lead beds have been identified as of Pliocene age. Still younger cycles are shown by valley-in-valley forms south of Wellington. Maze (1944) has drawn attention to downstepping erosional benches west of the Blue Mountains. Here is an example of multiple erosional bevels cut under a single continental cycle of erosion with repeated local uplift in the Blue Mountain region. (See King 1949, fig. 1.) Both the 'Australian' and

'Lake Eyre' cycles have been deformed in this manner west of the main divide with considerable modification of drainage systems.

The frequency of valley-in-valley forms in the landscapes of the coastal hinterland attests the episodic nature of the Kosciusko orogeny. At Mt. Kosciusko the 'Australian' pediplain was differentially elevated to 7000 feet, and at the Blue Mountains and New England Ranges to 3000-4000 feet, whence it continues into Queensland.

One may anticipate that mapping of erosional facets in the landscape of New South Wales will have more than usual interest.

In Queensland. The existing plains of western Queensland stand generally at a lower level than that of the laterite-capped 'Australian' pediplain. They may be ascribed to the earliest phase of the 'Lake Eyre' cycle, having been derived from the earlier cyclic plain, as descriptions plainly show, by scarp retreat and pedimentation following stream incision.

In the region tributary to the Gulf of Carpentaria the laterite-capped pediplain has been almost wholly destroyed, and so smooth is the 'Lake Eyre' planation through much of the west that on the border just south of the Tropic of Capricorn a step-faulted scarp of horizontal Ordovician sandstones 100 feet high is so prominent above the smooth plains as to have merited the name of the Toko Ranges.

The drainage systems of the 'Lake Eyre' cycle are choked with two sets of alluvia, an older, red, and a younger, grey. The former are often extensively eroded, as in the Carpentaria drainage. The latter, constituting vast inland deltas, are responsible for the amazing reticulatory drainage patterns of the Australian interior river systems. That of the Warrego has been described as "larger in area than the great deltas of the Nile, the Congo, the Indus, the Irrawaddy and the Mississippi." The abundant alluvia are due partly to the ready supply of debris from the Cretaceous and early Tertiary beds of the Great Artesian Basin and partly to the exceedingly low gradients of most of the streams. Of similar reticulations in the drainage patterns of strongly-flowing incised streams peripheral to the Barkly Tableland Whitehouse (1940a, p. 50) opines that they have been superimposed from earlier braided courses developed upon a plain. The plain in question may then have been an early phase of the 'Lake Eyre' cycle.

In the Moreton district, where the 'Australian' pediplain forms the crest at above 4000 feet, the 'Lake Eyre' cycle stands at 2600 feet. The line of the divide has been forced to the west by younger cycles acting from the coast, so that wind-gaps now appear at the heads of certain of the westward-flowing rivers (Wearne and Woolnough 1911, pp. 138-9). These events were followed by the usual extensive Kosciusko block movements. Andrews (1910) has emphasized the essential unity of 'post-Australian' erosional and tectonic events in eastern Australia, which should now be brought out by geomorphic mapping in the field.

All about Australia one of the last movements has been a drowning of 150-200 feet, remarkably like that which has affected the African continent.

Conclusion

The paper endeavours to demonstrate in Australia a connected and fairly uniform landscape history, and thereby to provide a geomorphologic skeleton upon which may be hung the multitude of physiographic facts which constitute the scenery of the country.

Clearly the landscapes fall into four sharply divided groups: (i) ancient landscapes ('Gondwana') older than the present configuration of Australia; (ii) a group of landscapes whose evolution began in Cretaceous and ended near the coasts in Miocene times, the extreme expression of which is the laterite-capped 'Australian' pediplain; (iii) more varied landscapes (initiated in the Miocene), the older of which have reached advanced planation, with destruction of much of the great 'Australian' pediplain; and (iv) a series of small local cyclic landscapes and phases following the powerfully differential movements of the Kosciusko orogeny, and later dislocations.

Basining and tilting sometimes caused uplift in one place and depression in another, as with the 'Gondwana' landscape of early Cretaceous time in Western Australia and the Queensland-New South Wales interior respectively.

It is suggested that, by submitting the landscape to investigation by quantitative methods, as by mapping the distribution of the main cyclic landscapes, a very complete story can be made out for the scenic evolution of Australia.

The skeleton being out of the cupboard, we must now confess that, with the exception of the fourth group of landscapes listed above, induced by the Kosciusko movements, the history is the same generally as that already demonstrated for South Africa (King 1949), where occur also: remnants of 'Gondwana' landscapes; an 'African' pediplain, most widespread of all the land-surfaces of the subcontinent, and developed principally between the Cretaceous and Miocene periods; and a third series of more varied, polycyclic landscapes.

Whether this correspondence is to be interpreted as a function of continental drift, or of other synchronous global influence, is a point for later solution.

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